Quantifying Contributions to U.S. Ozone Environmental Inequality

Robyn Chatwin-Davies, Amanda Pappin, Amir Hakami

Carleton University, Department of Civil and Environmental Engineering, Ottawa, Ontario, Canada

Carleton UNIVERSITY
Canada's Capital University

CMAS COMMUNITY MODELING & ANALYSIS SYSTEM

Goal of Study:

To quantify environmental inequality, specifically the relationship between ozone pollution and income, across the continental U.S.

1. INTRODUCTION

Various studies have investigated U.S. environmental inequality in the context of air pollution, and results have shown environmental risks are often correlated with socioeconomic status. This leads to disproportionate health burdens on vulnerable populations, who are in turn more susceptible to these risks (Clark, Millet & Marshall, 2014).
This study examines environmental inequality through the relationship of ozone pollution and income inequality.
By integrating ozone environmental inequality into CMAQ, this study serves as a proof of concept for further in-depth modeling of the relationship between emissions and environmental inequality. This will allow us to quantify how reduction of criteria air pollutants can have benefits for environmental inequality, and to determine how these benefits vary spatially across the U.S.

2. METHODOLOGY

2.1 DATA

Criteria air pollutants were modelled using CMAQ (v4.5.1):
- Model domain: Continental U.S. (CONUS) 36x36 km resolution with 34 layers
- Episode: May 1 – September 30, 2007
- Metrics:
  i. Daily maximum 8-hour average ozone (O_3) concentration

Socioeconomic status was modelled through income data taken from the U.S. Census Bureau:
- 12-month household income in 2014 inflation-adjusted U.S. dollars
- 2010-2014 American Community Survey 5-Year Estimates
- Population divided into 16 income bins
  i. Minimum: < $10,000
  ii. Maximum: > $200,000
- Number of household per income bin, for each census tract

Concentrations of pollutants were assigned to each census tract by linking them to CMAQ grid cells. Grid cells were linked based on the centroid of the census tract.

2.2 MEASURING INEQUALITY

There are several competing indices for measuring environmental inequality.
The most popular measure of income inequality is the Gini Coefficient, which is defined based on the Lorenz curve (Arnold, 2005).

The Lorenz curve:
- Plots the percentage of the total measure of interest (e.g. income or pollution) earned by the cumulative percentage of the population (DeMaio, 2007). See Figure 1.

The Gini Coefficient (G):
- Is the area between the Lorenz Curve and the line of perfect equality, divided by the total area under the line of perfect equality. See Figure 1 and Equation 1.
- Is defined mathematically as half of the relative mean absolute difference (Arnold, 2005). See Equation 2.
- Will range from 0 to 1, where 0 represents perfect equality, and 1 represents perfect inequality.

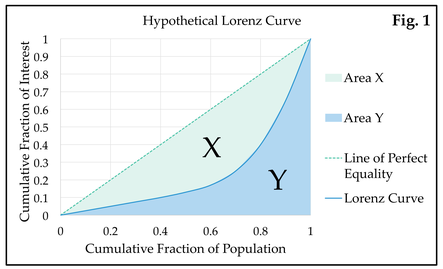


Figure 1. Hypothetical Lorenz Curve, showing the Gini Coefficient as a ratio of area X to the total area (X+Y)

Equation 1. The Gini Coefficient, based on the areas under the Lorenz Curve:

$$G = \frac{X}{X+Y}$$

Equation 2. The Gini Coefficient, based on the relative mean absolute difference:

$$G = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}|x_i - x_j|}{2n\sum_{i=1}^{n} x_i}$$

Where x_i is the measure of interest (e.g. income) of person i in a population of size n

The Lorenz Curve and Gini Coefficient only measure inequality across one dimension (Boyce, Zwickl, & Ash, 2015), and fail to provide information about two dimensions of inequality, such as the relationship between income and air pollution.

Toward this end, we propose modified Lorenz Curves that measures inequality on two dimensions, like those used by Sarabia & Jorda (2013):
- The cumulative fraction of ozone exposure earned, plotted against the cumulative fraction of population, sorted by income
- The cumulative fraction of ozone exposure earned, plotted against the cumulative fraction of income earned

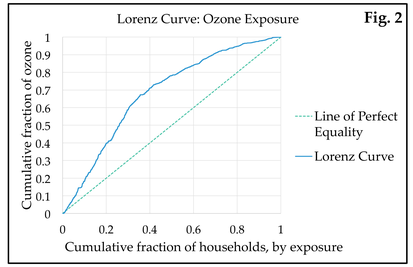
The Modified Gini Coefficient is calculated the same as the original Gini Coefficient, summarizing the inequality across multiple dimensions.

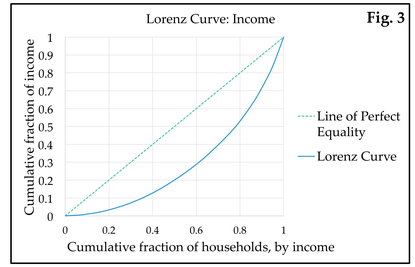
Combining the income data and air pollution data from CMAQ, four Lorenz curves were generated:

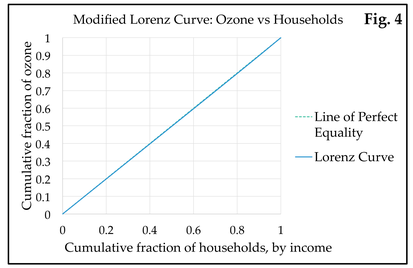
1. Traditional Lorenz curve, showing 1-D inequality in ozone exposure
2. Traditional Lorenz curve, showing 1-D income inequality
3. Modified Lorenz curve, showing 2-D inequality in ozone and population, sorted by income
4. Modified Lorenz curve, showing 2-D inequality in cumulative ozone and income

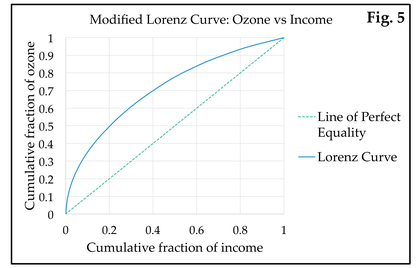
3. RESULTS

Figure 2. Inequality in Ozone Exposure, 1-D
Figure 3. Inequality in Income, 1-D
Figure 4. Inequality in Ozone and Population sorted by Income, 2-D
Figure 5. Inequality in Ozone and Income, 2-D









Lorenz curves were generated to show one- and two-dimensional measures of inequality, in Figures 2 - 5.
Gini Coefficients were calculated for each of the Lorenz Curves, and are summarized in Table 1 below.

Highlights:

- Mid-range levels of inequality are seen for Figures 2, 3, and 5. Inequality is not seen for Figure 4.
- The Gini Coefficient for Figure 3 agrees with The World Bank's calculations for the U.S., where G = 0.411 for 2013.
- Most notable is Figure 5, showing that the population that holds the poorest 10% of the income is exposed to approximately 35% of the overall ozone exposure. Meanwhile the population holding the richest 10% of the income is exposed to less than 5% of the overall ozone exposure.

Table 1. Summary of Gini Coefficients for 1-D and 2-D inequality scenarios

	Gini Coefficient
Figure 2. Inequality in Ozone Exposure, 1-D	0.366
Figure 3. Inequality in Income, 1-D	0.412
Figure 4. Inequality in Ozone and Population sorted by Income, 2-D	0.003
Figure 5. Inequality in Ozone and Income, 2-D	0.429

4. FUTURE WORK

- The study will be re-done with a finer resolution, using 4 nested grids centered over New York City: 36-km (continental U.S.), 12-km, 4-km, and 1-km
- Inequality measures will be integrated into CMAQ adjoint so as to map spatial sensitivities, and to see how various policy measures impact environmental inequality

5. CONCLUSION

- As a proof of concept, socioeconomic measures can be integrated into CMAQ to provide a measure of environmental inequality
- There are noticeable levels of income and exposure inequality across the U.S., where lower income populations are exposed to a higher burden of ozone pollution

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